Report on the Neutrino & Subterranean Science Workshop

NeSS2002

September 19-21, 2002

Washington DC.

http://www.physics.umd.edu/ness02/

Jordan A. Goodman
University of Maryland

NeSS 2002 and NFAC

- Charge to Workshop from OSTP
  - Organize a workshop on the IceCube neutrino telescope and "*research on neutrino collectors, including applications for underground research*"
- Request to National Research Council
  - Establish Neutrino Facilities Assessment Committee (NFAC) with a similar (but more restricted) charge.
- NeSS 02 and NFAC have been coordinated
  - Some NFAC members attended NeSS
  - Report on the NeSS conference went to NFAC

The *NeSS 2002* International Organizing Committee:

- John Bahcall, Institute for Advanced Study
- David Berley, University of Maryland
- Enrique Fernandez, University of Barcelona, Spain
- Thomas Gaisser, (chair) University of Delaware
- Jordan Goodman, University of Maryland
- Edward Kolb, Fermilab and University of Chicago
- Arthur McDonald, Queen's University Nat Lab, Canada
- Brian McPherson, New Mexico Tech
- William Press, Los Alamos Nat Lab
- Hamish Robertson, University of Washington
- Bernard Sadoulet, University of California, Berkeley
- Yoji Totsuka, University of Tokyo, Japan
- Michael Turner, University of Chicago
- Eli Waxman, Weitzman Institute, Israel

NeSS 2002 Details

- Truly interdisciplinary meeting
- Eleven working groups (that actually worked)
  - Six sub-disciplines of physical science
    - double beta-decay, proton decay, neutrino oscillations, dark matter, solar neutrinos, astrophysical and cosmological neutrinos;
  - Three sub-disciplines of geoscience
    - geology, geoengineering and geobiology
  - Plus - national security, and education and outreach.
- 320 participants from all over the world
  - Despite the short lead-time
- Working groups wrote summaries and presented findings to the meeting.

NeSS 2002 Agenda

Thursday, September 19, 2002

Opening Remarks- **Bordogna**

NSF View of NeSS 2002- **Dehmer**

Theoretical perspectives on fundamental physics underground - **Ellis**

Theoretical perspectives on astrophysics from underground- **Turner**

Experimental Perspectives on Underground Science- **Freedman**

Perspectives on Underground Geo-Science and Engineering- **Onstott**

Report on NRC Study- **Barish**

Parallel Working Group Sessions I

Friday, September 20, 2002

Parallel Working Group Sessions II

US High Energy Neutrino Experiments in Ice- **Halzen**

Friday, September 20, 2002

Other High Energy Neutrino Experiments -including ANTARES, NESTOR, NEMO, Baikal – **Fernandez**

Subterranean Science- **Haxton**

Non-US Subterranean Plans-**Kajita**

US San Jacinto- **Sobel**

US Carlsbad Underground National Laboratory- **Haines**

US Subterranean Facility at Homestake- **Haxton**

Saturday, September 21, 2002

Parallel Sessions III - Working Group Windups

Summaries of the Working Groups

Future Directions- **Bahcall**

Concluding Remarks- **Gaisser**

Consensus of Working Groups

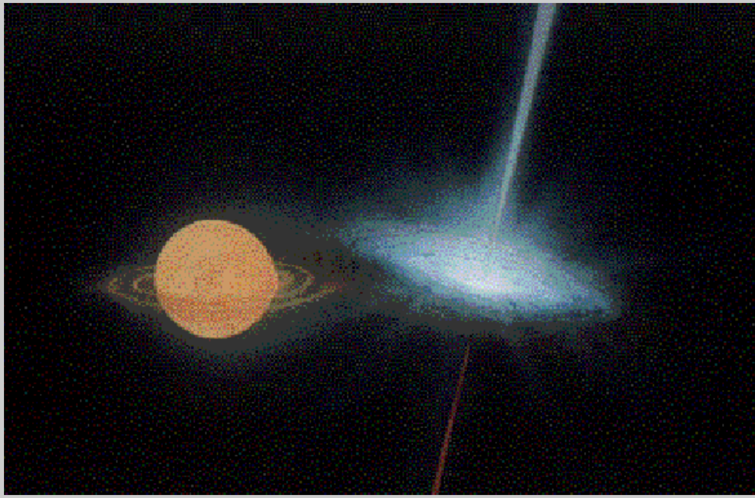
- The great potential and intense activity in this field demand the creation of a program for science done underground, including geobiology, geophysics, physics and astronomy.
- Concerning the two major elements of the charge to the workshop there was unanimous agreement of the working group leaders that: ***Both of these efforts should be supported.***
  - **IceCube** will probe the sources of the highest energy particles by observing high-energy neutrinos from distant regions of the Universe.
  - Experiments to detect low energy neutrinos or search for dark matter and rare processes in the low-background environment of an **underground laboratory** are different in design and goals from IceCube.
- There was great enthusiasm for the physics and geosciences goals that could benefit from the existence of a national underground laboratory as well as the national security benefits.
- Plus it was clear that a new program in underground science could have a coordinated education and outreach benefit built into all aspects of the program from its inception.

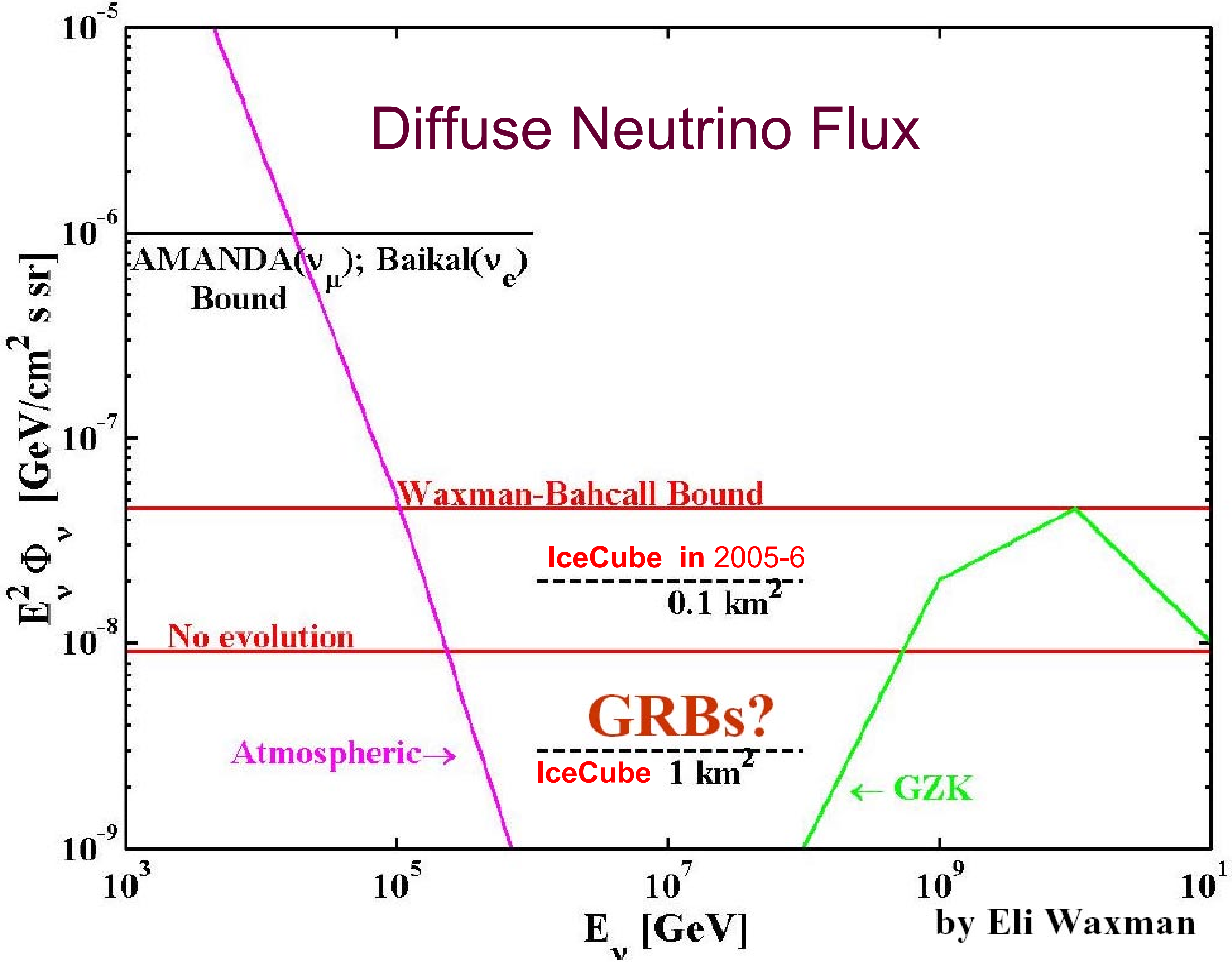
Working Group Summaries

NeSS2002

Astrophysical Neutrino Science

- Use high energy neutrinos to find and study the sources of high energy cosmic rays
- 1 TeV – 10 PeV is the most favorable range for observation of extreme sources:
  - Gamma-ray bursts
  - Active galactic nuclei
  - Microquasars
- WIMP / dark matter detection





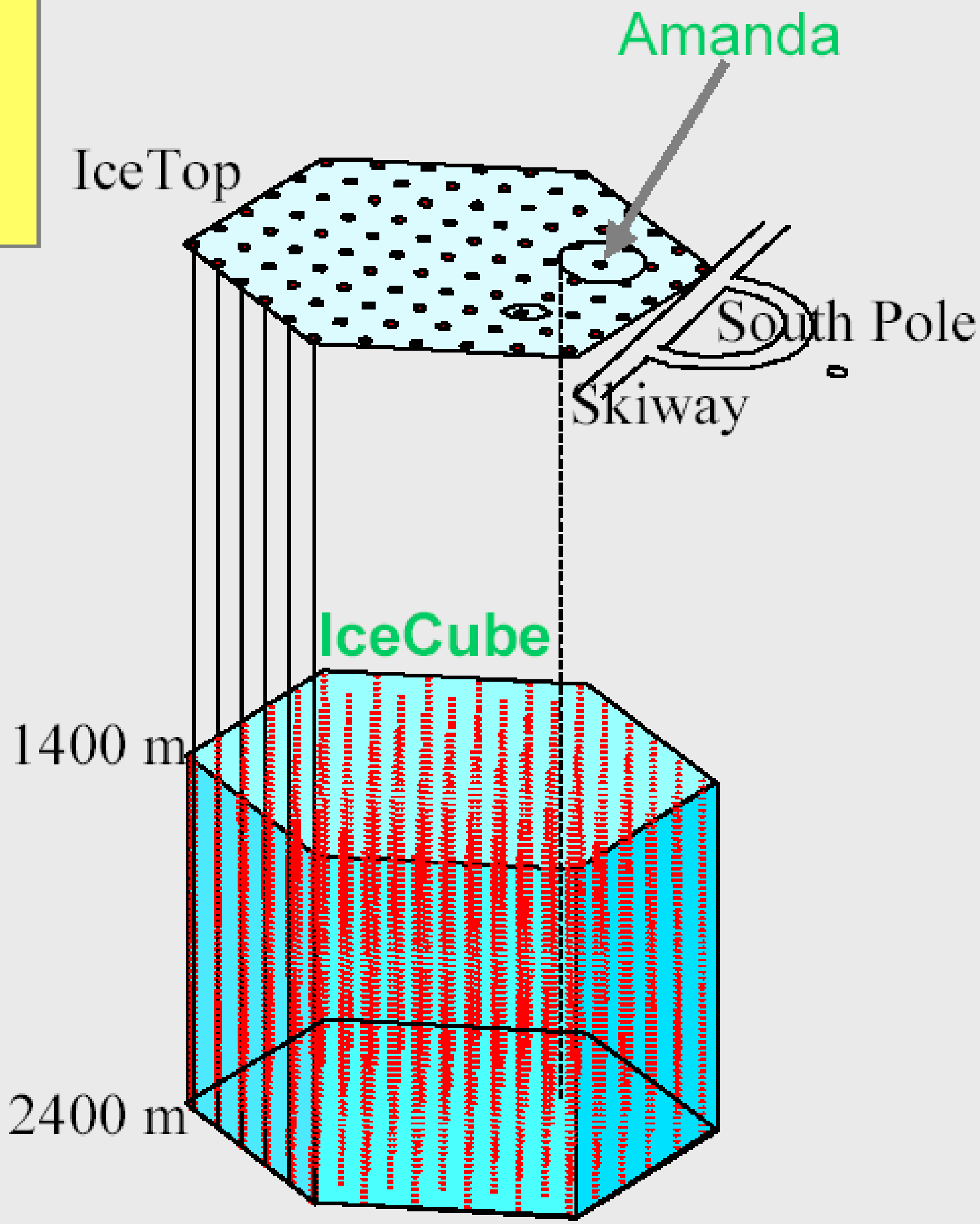
Diffuse Neutrino Flux
$E_\nu^2 \Phi_\nu$ [GeV/cm^2 s sr]
AMANDA(ν_μ); Baikal(ν_e)
Bound
Waxman-Bahcall Bound
IceCube in 2005-6
0.1 km^2
No evolution
GRBs?
Atmospheric→
IceCube 1 km^2
← GZK
E_ν [GeV]
by Eli Waxman

Astrophysical Neutrinos

- Require a detector volume of the order 1km^3
  – place detectors in a large, natural volume of clear water or ice.
- Detect neutrinos in the energy range above the background of atmospheric neutrinos
  – Atmospheric neutrinos serve for calibration in the TeV energy region.
- Consensus: the science warrants both
  – Ice, at the South Pole.
  – Water, in the northern hemisphere
  – Northern hemisphere effort was started after IceCube approval!

IceCube Design

- Design of all major IceCube components builds on extensive experience with AMANDA
- IceCube designed to detect neutrinos of all flavors at energies from 10^7 eV (SN) to 10^{20} eV & beyond
- Instrumented volume: One km^3
  - 80 strings
  - 4800 PMTs in *Digital Optical Modules* (DOMs)
  - 160 IceTop tanks
  - 1400 m to 2400m depth
  - Not a cube, but there are no rappers named IceHexagonoid



Double Beta Decay

- Neutrinoless double beta decay:
  - is the most promising technique for determining the overall scale of neutrino mass.
  - Recent neutrino oscillation results provide compelling arguments for new experiments with 100-fold increases in sensitivity.
  - Several promising experiments using distinct technologies have reached an advanced stage of development.
  - Because the ultimate sensitivity of new techniques is difficult to anticipate - **more than one** next-generation experiment must be supported.

Double Beta Decay

- Neutrinoless double beta decay
  - tests if $\nu = \bar{\nu}$
  - Searches for new CP violating phases, and a variety of beyond the- standard-model phenomena.
- The 0.01 eV goal requires:
  - sensitivity to half lives in excess of 10^{28} years.
  - source masses ~1000 kg
  - unprecedented suppression of cosmic ray and radioactivity backgrounds.
  - Several of the most promising experiments need enriched isotopes. Thus the scale and cost of future experiments are significant.

Double Beta-Decay Experiments

completed
current
future

$\beta\beta$ Exps.	Isotope	Technique	Mass(kg)	Enriched	$\langle m_\nu \rangle$ eV	m.w.e.	Location
Heid/Moscow	^{76}Ge	Ge crystal	9.9	86%	$\leq$0.40	2700	Gran Sasso
IGEX	^{76}Ge	Ge crystal	$\sim$ 9	86%	$\leq$0.44	2450	Canfranc, Sp.
UCI	^{82}Se	TPC with foils	0.014	97%	$\leq$7.7	290	Hoover Dam
ELEGANT	^{100}Mo	drift chamber-scintillators	0.20	94.5%	$\leq$2.7	1800	Oto, Japan
Kiev	^{116}Cd	$CdWO_4$ crystals	0.09	83%	$\leq$3.3	1000	Ukraine
Missouri	^{128}Te	geochemical	Te ore	no	$\leq$1.5	N/A	N/A
Milano	^{130}Te	cryogenic TeO_2 crystals	2.3	no	$\leq$2.6	2700	Gran Sasso
Cal-UN-PSI	^{136}Xe	high pres. TPC	2.1	62.5%	$\leq$3.5	3000	Switzerland
UCI	^{150}Nd	TPC foils	0.015	91%	$\leq$7.1	290	Hoover Dam
NEMO3	^{82}Se, ^{100}Mo, ^{116}Cd, ^{150}Nd	drift chamber-scintillator	1-10	yes	$\sim$0.1	4800	Frejus, France
CUORICINO	^{130}Te	cryogenic TeO_2 crystals	11.5	no	$\sim$0.1	2700	Gran Sasso
GENIUS	^{76}Ge	400 Ge cystals	1000	yes	0.01	2700	Gran Sasso
MAJORANA	^{76}Ge	400 Ge crystals	500	yes	0.02	$\geq$4000	
CAMEO	^{82}Se,...	Borexino CTF	$\sim$1	yes	$\sim$1		Gran Sasso
MOON	^{100}Mo	scintillator+foils	3400	no	0.03	$\geq$2500	
CUORE	^{130}Te	1020 cryogenic TeO_2 crystals	210	no	0.02		Gran Sasso
EXO	^{136}Xe	high pres. TPC	10000	yes	0.01	$\geq$2000	
DBCA-II(2)	^{150}Nd	drift chamber	18	yes	$\sim$0.05		Oto, Japan

Dark Matter

- Detect the ~30% of the Universe that is:
  - Not visible
  - Non baryonic
- Planned experiments will:
  - probe the parameter space allowed by current theory
  - potentially open the field of WIMP astronomy

Dark Matter

Current and Future Experiments

Technology /Collab. Name	CURRENT Fiducial Mass Goal / (Now)	(2001–) Funding source	Location	PROJECTED Mass Goal	(2005–) Location
Liquid Xe					
XENON	100 kg (-)	US	**	1000 kg	**
ZEPLIN	30 kg (3 kg)	UK/US	Boulby,UK	1000 kg	Boulby,UK
XMASS	20 kg (1 kg)	Japan	Kamioka,Japan	1000 kg	**
Cryogenic (T<1K)					
CDMS/CryoArray	7 kg (1 kg)	US	Soudan,US	1000 kg	**
EDELWEISS	7 kg (0.7 kg)	France	Frejus,France	35 kg	Frejus,France
EuroCryo Collab		Europe	**	1000 kg	**
Gas TPC					
DRIFT	1 kg (0.2 kg)	US/UK	Boulby,UK	100 kg	**
HP Ge					
MAJORANA	40 kg (2 kg)	US	**	500 kg	**
GENIUS	40 kg (5 kg)	Europe	Gran Sasso,Ity	1000 kg	Gran Sasso,Ity

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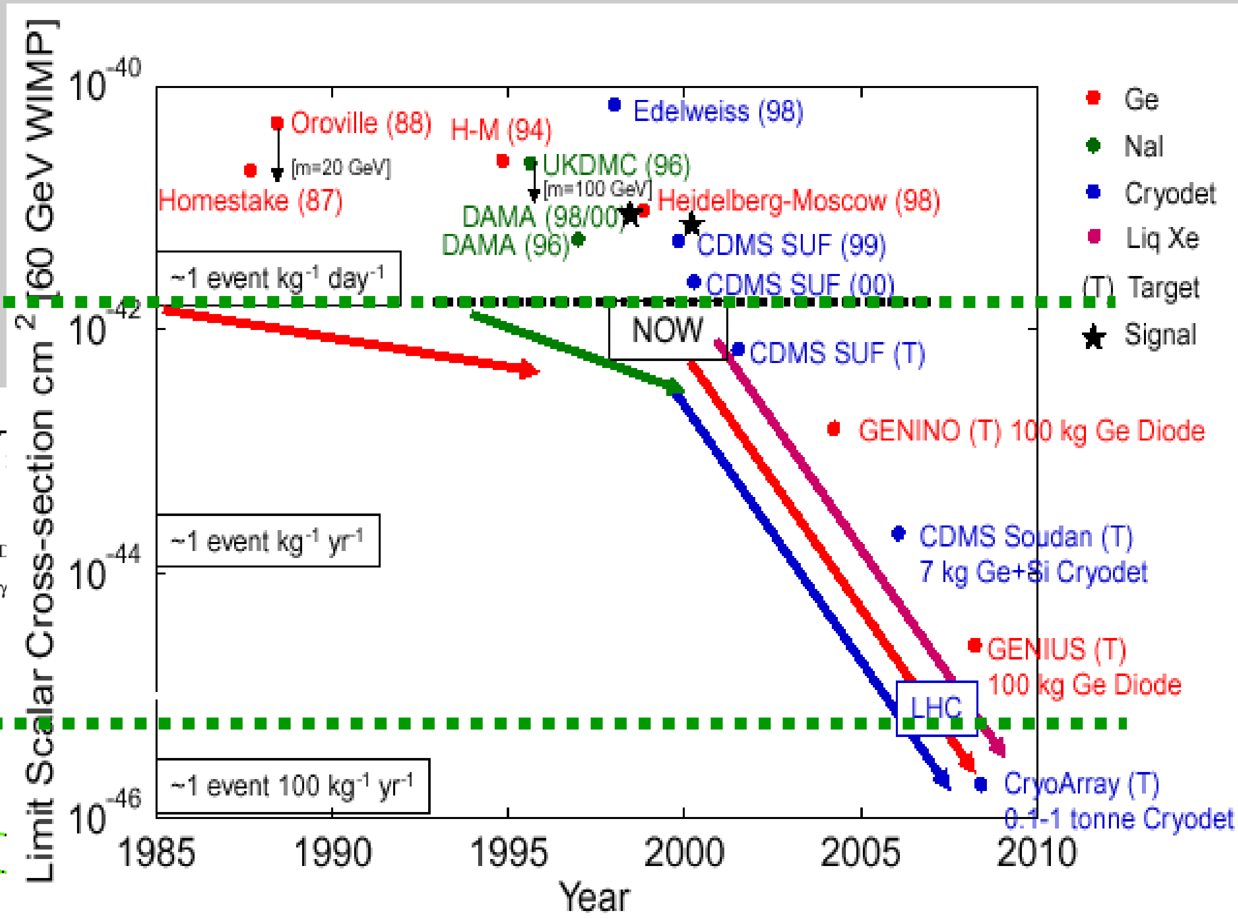
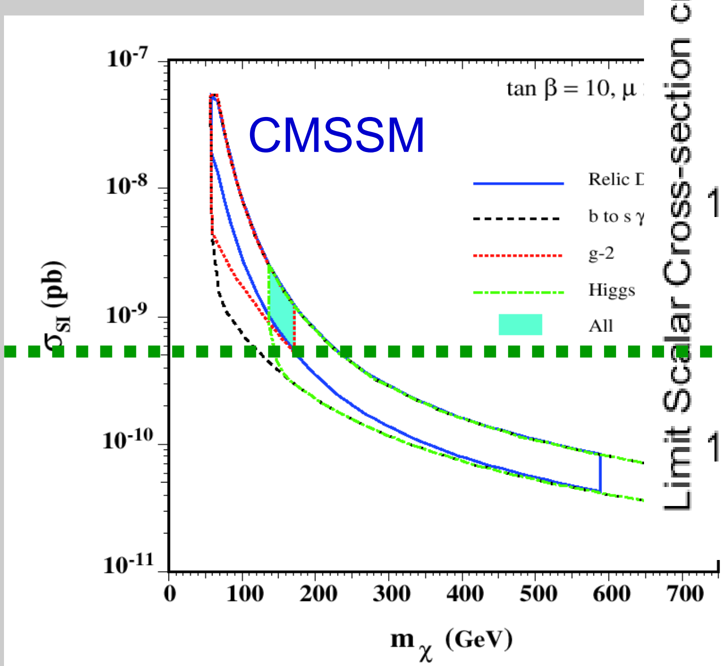
WIMP Sensitivity





astro-ph/pdf/0106/0106200

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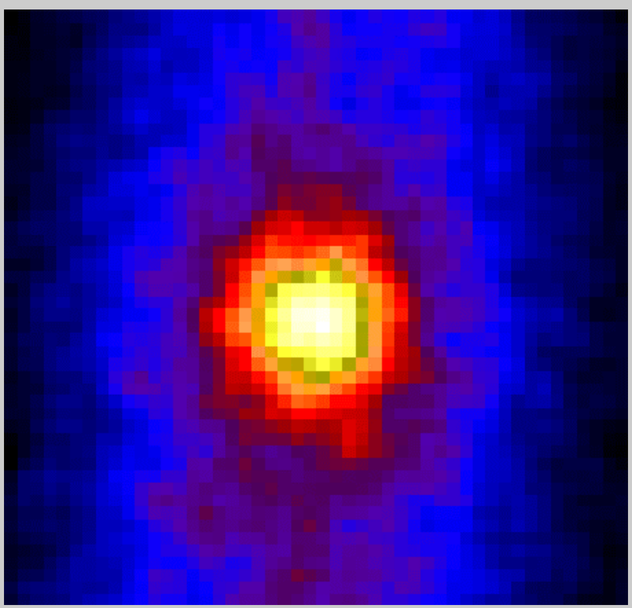
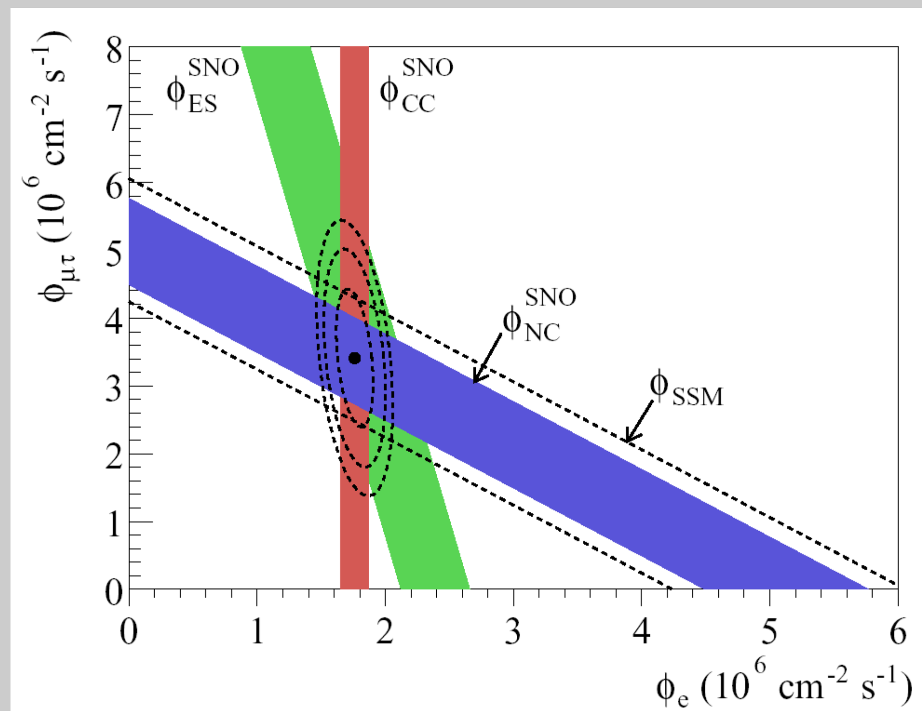
Solar Neutrinos

- More to do on solar neutrinos:
  - Build on recent successes
  - Measure processes and parameters of neutrino transformations.
  - Use high-intensity underground accelerator to understanding nuclear reactions that power the Sun and supernovae.





Solar Neutrinos

- Future solar neutrino experiments will:
  - make progress in understanding the complete neutrino mixing matrix
  - provide a stringent test of the Standard Solar Model.
  - require a deep (>4000 mwe) and dedicated underground laboratory
- An underground accelerator facility would allow significant progress in our understanding of stellar processes
- This research program would benefit significantly from the centralized infrastructure at an underground lab

Neutrino Oscillations

- Measure with precision **neutrino oscillations and CP violation** with long baseline accelerator neutrino beams
- Goals: to answer
  - Why are the masses so small?
  - Are there additional “sterile”neutrinos?
  - Why are the mixings so large?
  - What is the connection between the lepton and baryon sectors?
  - Can ν CP violation explain the baryon / antibaryon asymmetry?

Neutrino Oscillation Measurements

Solar and Atmospheric results determine Δm_{12}^2, θ_{12}, Δm_{23}^2, θ_{23}

$$
\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}
=
\begin{pmatrix}
c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\
-s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\
s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13}
\end{pmatrix}
\begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}
$$

$$
=
\begin{pmatrix}
1 & & \\
 & c_{23} & s_{23} \\
 & -s_{23} & c_{23}
\end{pmatrix}
\begin{pmatrix}
c_{13} & & s_{13}e^{i\delta} \\
 & 1 & \\
-s_{13}e^{i\delta} & & c_{13}
\end{pmatrix}
\begin{pmatrix}
c_{12} & s_{12} & \\
-s_{12} & c_{12} & \\
 & & 1
\end{pmatrix}
\begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}
$$

Atmospheric: θ_{23}

???

Solar: θ_{12}

Need to measure: Sign of Δm_{23}^2 , ~~CP~~ phase δ , θ_{13} ($\nu_e \rightarrow \nu_\mu$)

Neutrino Oscillation Roadmap

Stage 0: Current near term program

NuMI (K2K) checks atmospheric oscillations and measures Δm^2_{23} to about 10%

MiniBooNE makes definitive check of LSND and measures associated Δm^2

Stage 1 - Constrain / measure $\sin^2 2\theta_{13}$

NuMI /MINOS on-axis probes $\sin^2 2\theta_{13} > 0.06$ @ 90%CL

NuMI/JHF offaxis could go down to $\sin^2 2\theta_{13} > 0.01$ @ 90%CL

FNAL to NUSL with 100kton detector?

Stage 2 - Measure CP violation and sign of Δm^2_{23} with conventional superbeams and very large detectors (500 to 1000ktons)

Must have $\sin^2 2\theta_{13} > 0.01$

Need to measure $P(\nu_\mu \to \nu_e)$ then $P(\bar{\nu}_\mu \to \bar{\nu}_e)$

Need increased rate (especially for $\bar{\nu}$'s) $\Rightarrow$ Need high intensity proton sources

Stage 3 - Measurements with Neutrino Factory

Map out CP violation with precision for $\sin^2 2\theta_{13} > 0.01$

Probe $\nu_\mu \to \nu_e$ transitions down to $\sin^2 2\theta_{13} > 0.001$

Proton Decay

- Current higher unification models have **proton decay** as a compelling prediction at a rate not reached by previous detector generations.
- The next generation of **proton decay** detector needs to be a factor of nearly 20 times bigger to reach the predicted lifetime range in a wide variety of modes.
- Unique window to extremely high-energy physics (sensitive to mass scales at 10^{15} GeV)
- Many modifications of GUT predict proton decay within the reach of next generation (~1Mt) experiments

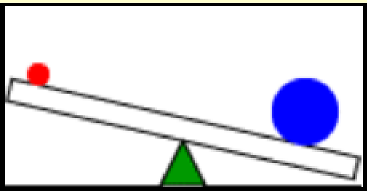
$p \rightarrow e^+ \pi^0$

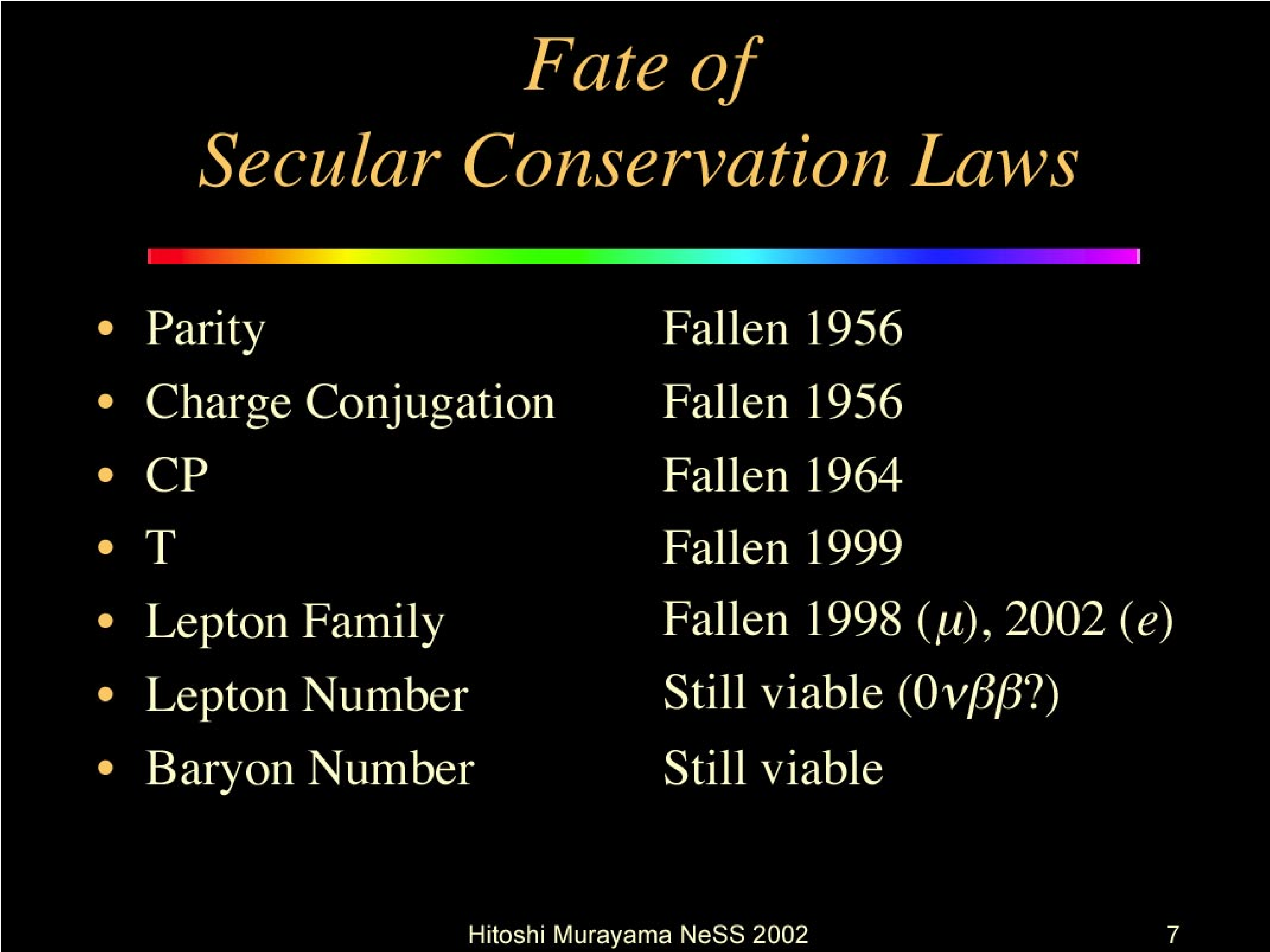
- SuperK: $\tau(p \rightarrow e^+\pi^0) > 1.6\times10^{33}$year
  (90% CL, 25.5 kt year)
- Minimal SUSY GUT:
  $\tau(p \rightarrow e^+\pi^0) = 8\times10^{34}\text{year}\,(M_V/10^{16}\text{GeV})^4$
  $M_V > 1.4\times10^{16}$GeV
- Flipped SU(5):
  $\tau(p \rightarrow e^+\pi^0) = 4\times10^{35}\text{year}\,(M_V/10^{16}\text{GeV})^4$
  $M_V > 2.6\times10^{15}$GeV
- 5-D orbifold GUT: $\tau(p \rightarrow e^+\pi^0) \approx 10^{34}$year

May well be just around the corner

$$\begin{pmatrix} \nu_L & \nu_R \end{pmatrix} \begin{pmatrix} & m_D \\ m_D & M \end{pmatrix} \begin{pmatrix} \nu_L \\ \nu_R \end{pmatrix}$$

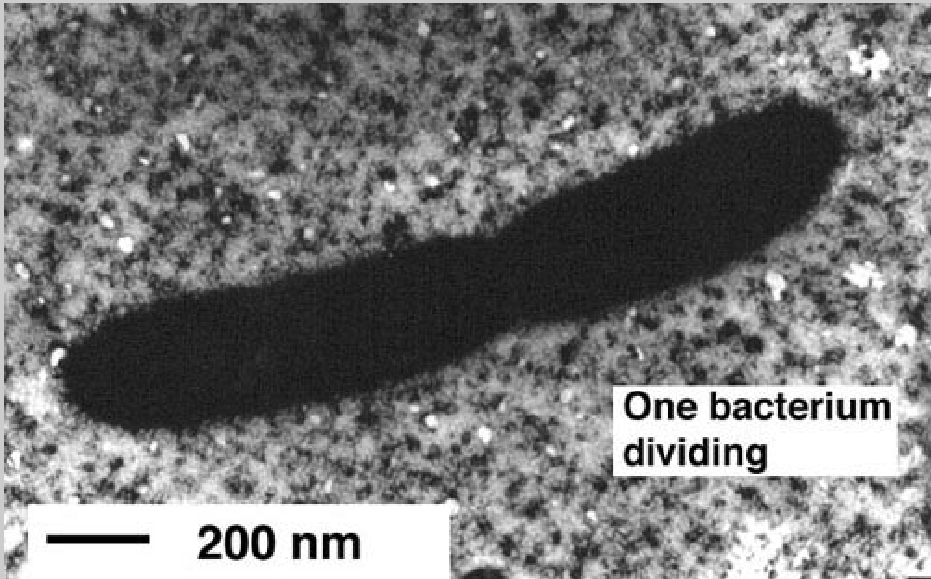
$$m_\nu = \frac{m_D^2}{M} << m_D$$

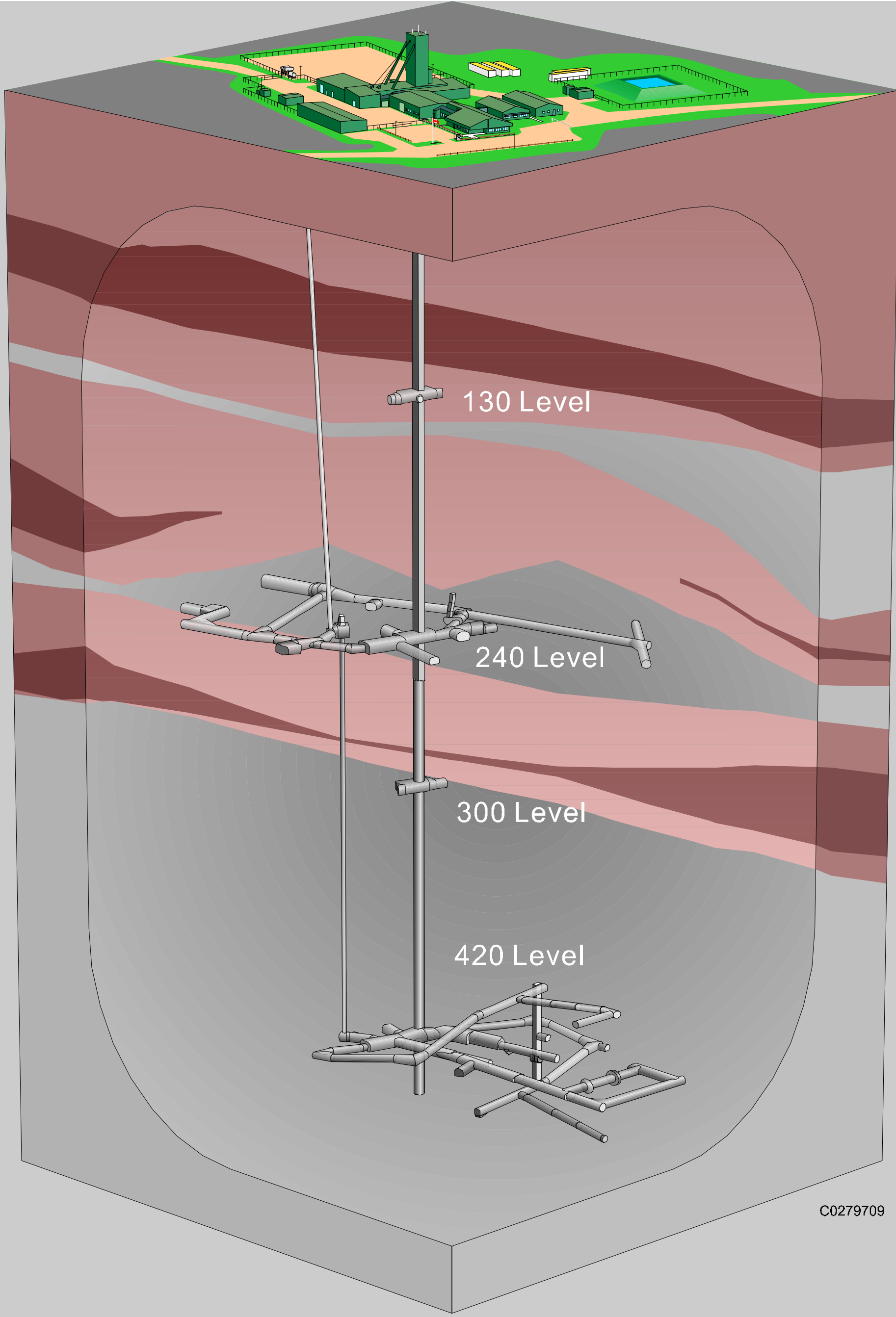



Fate of
Secular Conservation Laws
Parity
Fallen 1956
Charge Conjugation
Fallen 1956
CP
Fallen 1964
T
Fallen 1999
Lepton Family
Fallen 1998 (μ), 2002 (e)
Lepton Number
Still viable ($0\nu\beta\beta$?)
Baryon Number
Still viable
Hitoshi Murayama NeSS 2002
7

Geo-Sciences

- Theme: Coupled processes in the Earth at depth
  - Life at depth
  - Fluid flow and transport at depth
  - Rock deformation at depth
- Significant potential for:
  - scientific and engineering innovation
  - Education and outreach





Proposed New Approach:

Develop a US laboratory and observatory underground, inside the earth.

Much like surgery permits a physician to examine internal bones and organs recognized on X-rays or CAT scans, NUSL will be a fully instrumented, dedicated laboratory and observatory for scientists to examine Earth's interior.

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Microbiology in Extreme Environments

- Recent discoveries of the adaptability of microbial life: ability to survive and evolve in environments characterized by high/low temperatures, extreme pressures, acidity, and salinity
- Evolution in isolated environments
    - A model for astrobiology: as the earth has exchanged matter with other planets, is this a mechanism for the migration of life?
    - What is the probability that life can survive in a hostile environment, and how do the stresses affect adaptation?
    - On earth, can the genomic databases of key microorganisms be used to link evolutionary sequences with geochemical and/or paleontological events?
- Terrestrial extremophiles are the most accessible model for life that may exist elsewhere

Fractures are Key to Many Processes

- Fluid Flow
- Rock Strength
- Heat Flow
- Chemical Transport
- Ore Formation
- Faults & Earthquakes
- Biosphere for deep life to colonize and pathways for nutrient transport.

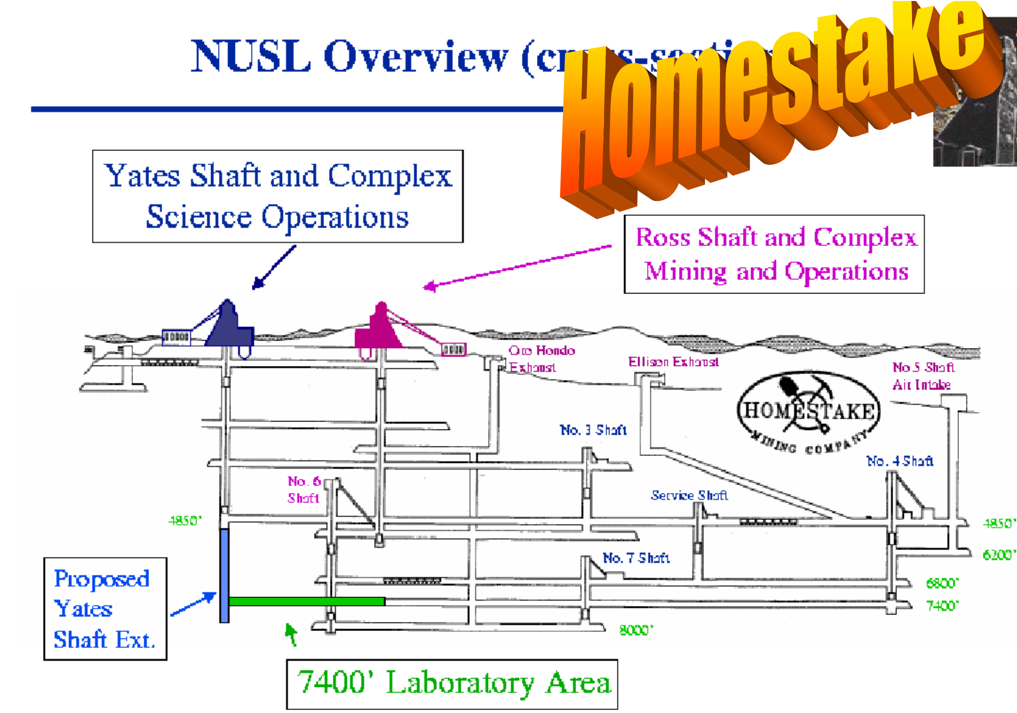
Mauna Loa fissure eruption, D.A. Clague

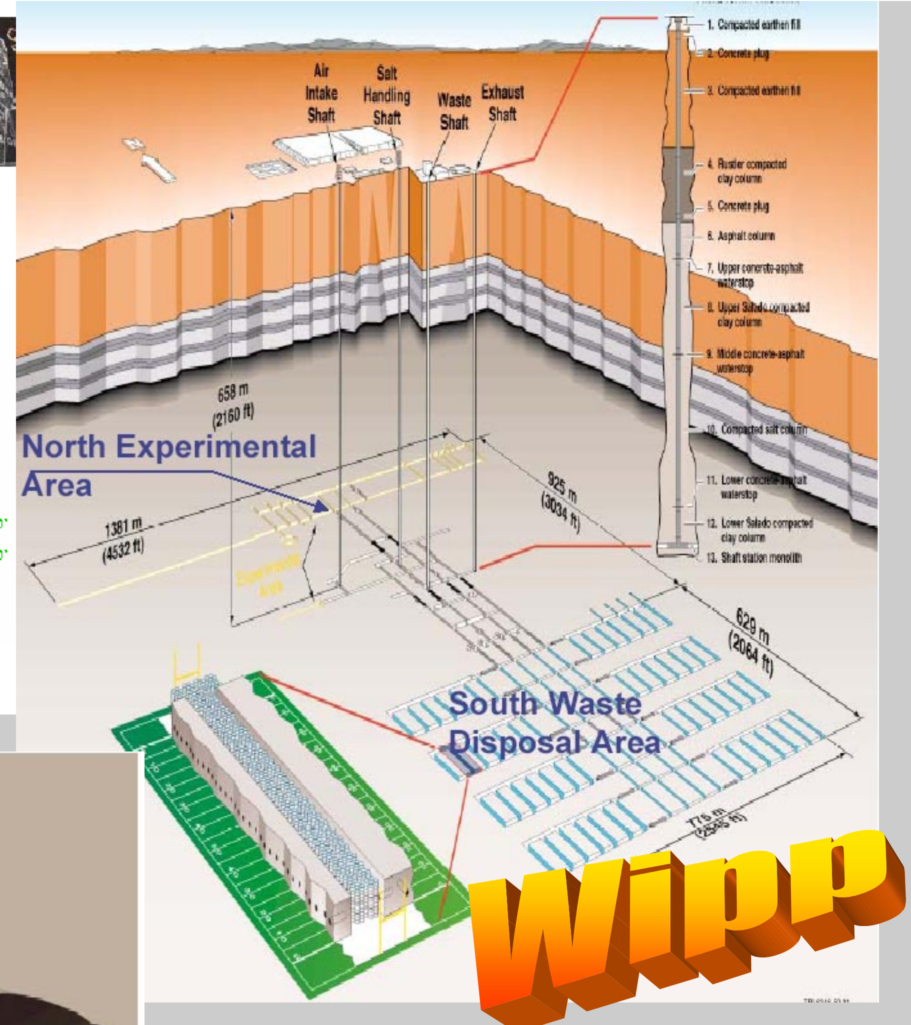
Education and Outreach

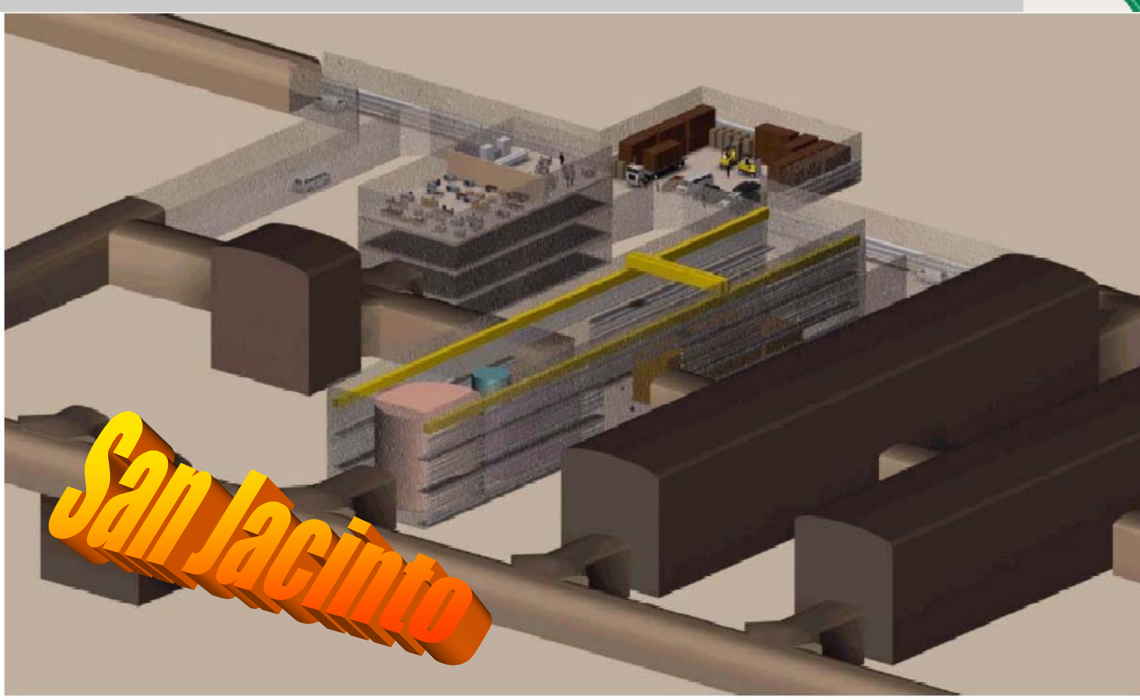
- Most E&O projects suffer because:
  - – Uncoordinated, unfocused – “goal creep”
  - – Not possible to offer sustained programs that pursue goals in depth
  - – Almost no research and evaluation
  - – Workforce issues not effectively addressed
  - – Strategies do not optimize resources, e.g., scientists’ time

Five "NeSS factors" afford critical opportunities to demonstrate how to do E&O right:

1. Ground-up coordinated context
2. Fundamental origins questions pursued in remote & extreme frontier environments
3. Cutting-edge multidisciplinary science
4. Collaborative multi-site effort
5. Facilities located in areas inhabited by underserved groups







Multiple sites discussed for underground lab:

- Homestake
- WIPP
- San Jacinto

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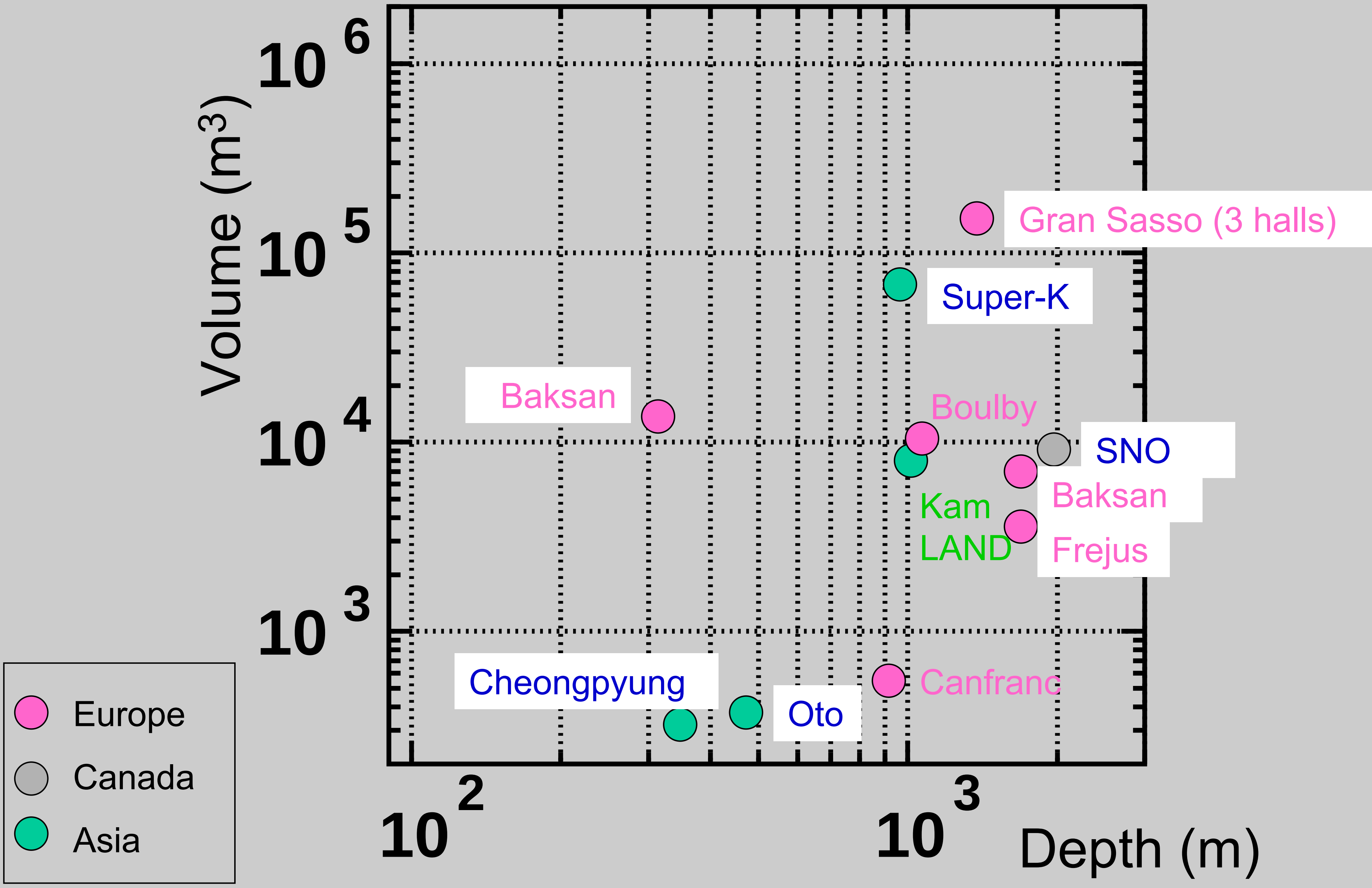
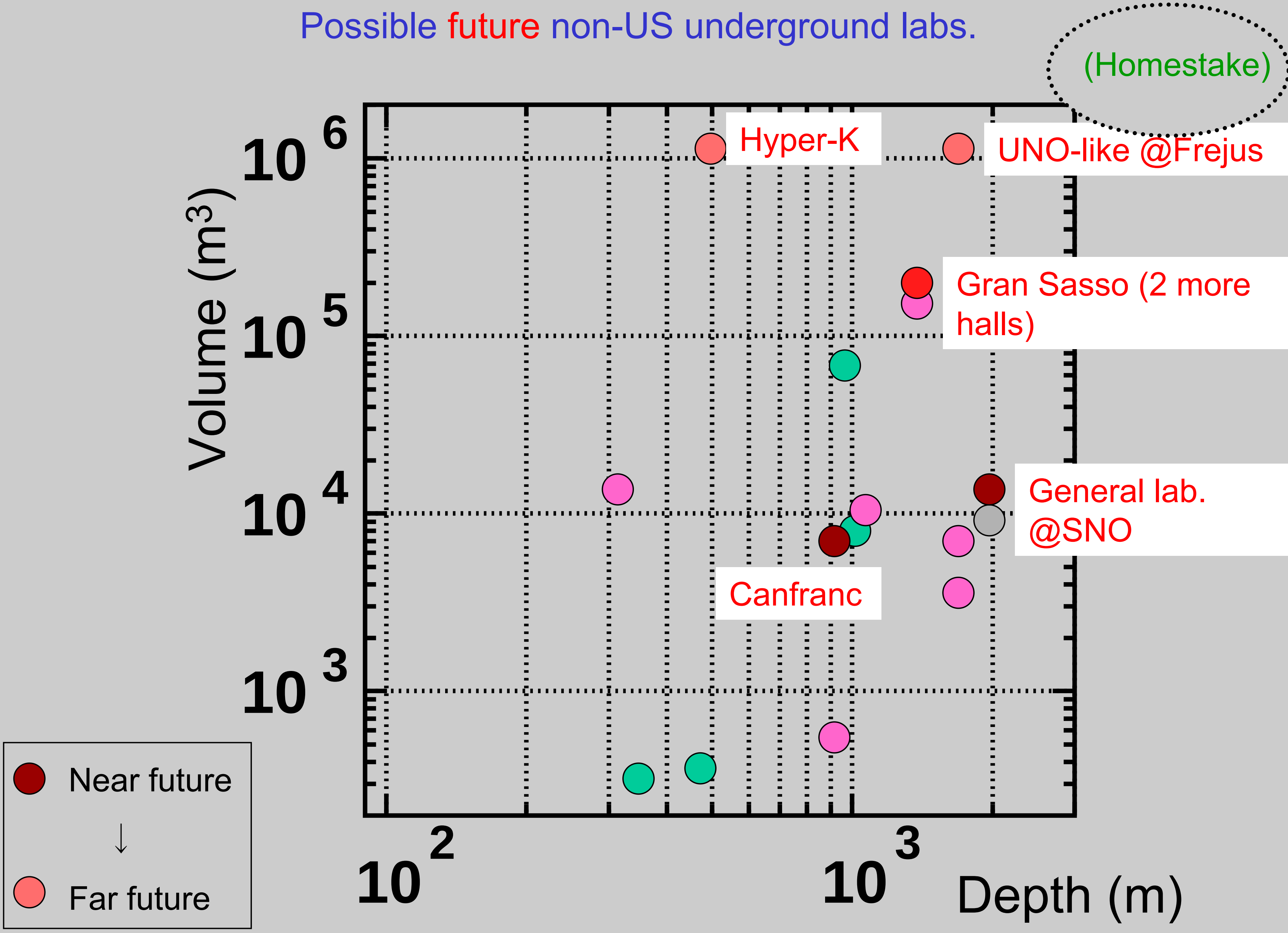
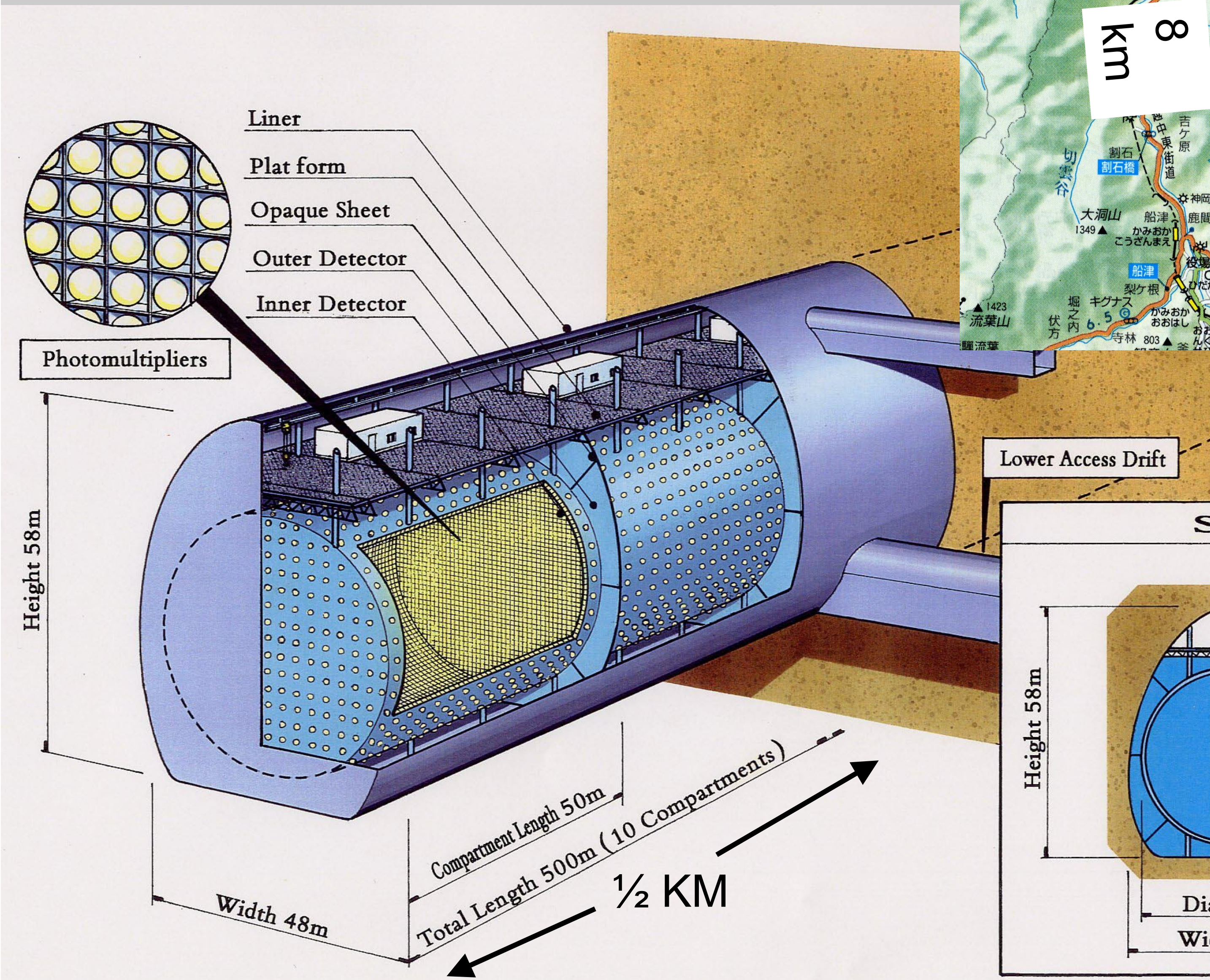
Summary of the present non-US underground labs.



Possible future non-US underground labs.



Hyper-Kamiokande



½ KM

Super-K (Depth: 2700mwe)

Hyper-K

Depth:

1400 –1900mwe

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Conclusions of *NeSS* 2002

- There is great potential and intense activity in this field.
- Consensus for creation of a **program** for science done underground, including
  - Geobiology
  - Geophysics
  - Physics
  - Astronomy
- IceCube will open a new window by observing high-energy neutrinos from distant regions of the Universe.
- There was unanimous agreement that both of these efforts should be supported.

Science Underground

- **IceCube**
  - Ultrahigh energy cosmic ray sources
  - Study of extreme objects – AGN, GRB, Supernova, μquasars
  - Wimp detection
- **Neutrino-less double beta decay**
  - Is the neutrino is own antiparticle
  - Absolute neutrino mass scale
- **Dark matter experiments:**
  - Detection of dark matter
  - SUSY
  - Wimp Astronomy
- **Solar neutrinos**
  - Precision measurements of neutrino mixing
  - Tests of Standard Solar Model

Science Underground

- **Neutrino oscillations and CP violation:**
  - Baryon Asymmetry / Leptogenesis
  - Precision measurements of standard model parameters - $\theta_{1\text{-}3}$
- **Proton decay:**
  - Nucleon Lifetime
  - Heavy neutrino mass
- **Geosciences laboratory:**
  - Coupled processes in the Earth at depth
  - Growth and survival of novel microscopic life forms
  - Fluid flow, rock deformation and geochemical processes.
- **Low background counting and seismic detection:**
  - National security – isotope identification
  - Nuclear blast detection
- **Education and Outreach**
  - Integrated ground up approach

Reports Online

- Conference Website has the presentations

http://www.physics.umd.edu/ness02/

- The documents can be found at:

http://umdgrb.umd.edu/goodman/ness02/

- This presentation

http://umdgrb.umd.edu/goodman/ness02

http://www2.physics.umd.edu/~goodman/